Chapter A1: Ecological Risk Assessment Framework

Introduction

EPA has defined ecological risk assessment as "a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (U.S. EPA, 1998b). It is an approach to impact assessment that involves explicit evaluation of the data, assumptions, and uncertainties associated with an impact analysis. Risk assessments range in level of analysis and data requirements, depending on management goals, data availability, and stakeholder concerns.

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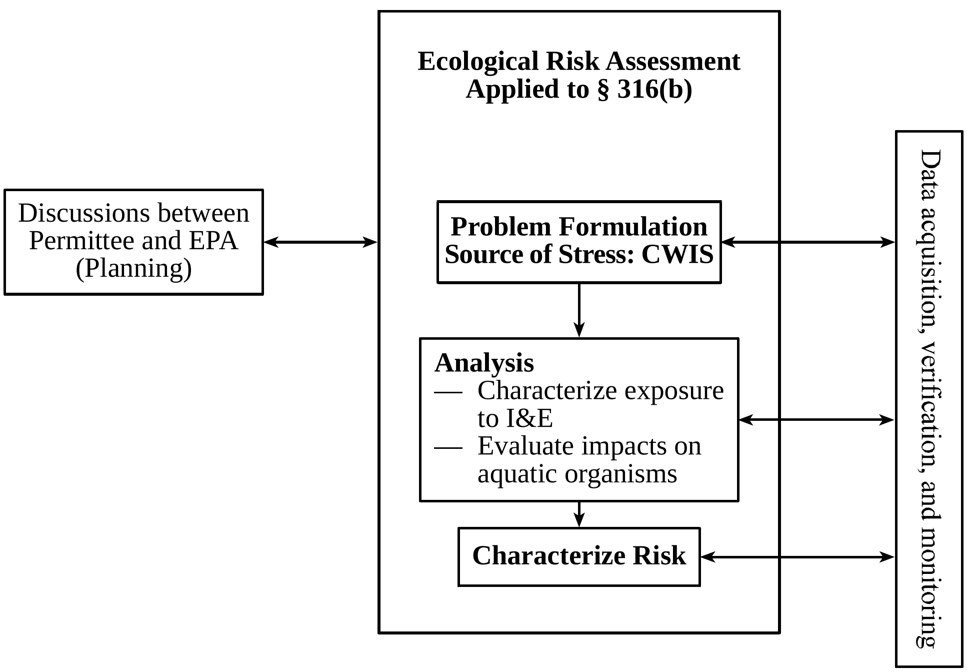
In the context of evaluating the impacts of cooling water intake structures (CWIS) under § 316(b), the key stressors of interest for an ecological risk assessment are the impingement and entrainment (I&E) of aquatic organisms. The following sections outline the three phases of ecological risk assessment (problem formulation, analysis, and risk characterization) as they apply to EPA's § 316(b) case studies (see Figure A1-1).

Figure A1-1: EPA's Framework for Ecological Risk Assessment Applied to § 316(b)



Adapted from U.S. EPA, 1998b.

A1-1 Problem Formulation

The problem formulation phase of an ecological risk assessment defines the problem to be evaluated and develops a plan for analyzing available data and characterizing risk (U.S. EPA, 1998b). This involves formulating a conceptual model of the relationships between stressors and receptors, selecting assessment and measurement endpoints, and developing a plan for the analysis of exposure and risk. In the context of § 316(b), the primary stressors associated with CWIS are I&E and the receptors are the aquatic organisms that are exposed to I&E. Figure A1-2 is a conceptual model indicating the primary and secondary ecological effects that result from the exposure of aquatic organisms to I&E.

An assessment endpoint is any ecological entity of concern to stakeholders (U.S. EPA, 1998b). Ecological entities to be assessed may include one or more entities across a range of levels of biological organization, including individuals, subpopulations, populations, species, communities, or ecosystems. Measurement endpoints are the attributes of an assessment endpoint that are evaluated in a risk assessment. Attributes of concern may include individual survival, population recruitment, species abundance, species diversity, or ecosystem structure and function. Ideally, assessment endpoints should include all species directly and indirectly affected by a CWIS. Potentially affected organisms include fish, shellfish, planktonic organisms, sea turtles, and marine mammals. In most cases, assessment endpoints for the § 316(b) case studies include only fish and shellfish species because these species are the focus of most facility studies. Measurement endpoints that should be included in all § 316(b) risk analyses include annual losses of individual organisms, adult equivalent losses, lost fishery yield, and production foregone, as described in detail in Chapter A4.

A1-2 Analysis

The analysis phase of an ecological risk assessment focuses on the characterization of (1) exposure to one or more stressors and (2) the ecological effects that are expected to result from exposure (U.S. EPA, 1998b).

A1-2.1 Characterization of Exposure of Aquatic Organisms to CWIS

Exposure characterization describes the potential or actual co-occurrence of stressors and receptors (U.S. EPA, 1998b). In the case of CWIS, characterization of exposure involves description of facility characteristics that influence rates of I&E, and the physical, chemical, and biological characteristics of the surrounding ecosystem that influence the intensity, time, and spatial extent of contact of aquatic organisms with a facility's CWIS.

Exposure of aquatic organisms to I&E depends on factors related to the location, design, construction, capacity, and operation of the facility's CWIS (U.S. EPA, 1976; SAIC, 1994; SAIC, 1995; SAIC, 1996a and b). Table A1-1 lists facility characteristics as well as characteristics of species and the surrounding environment that influence when, how, and why aquatic organisms may become exposed to and experience adverse effects of CWIS. These characteristics are described in the following sections based on information provided in EPA's 1976 § 316(b) development document (U.S. EPA, 1976) and background papers developed for EPA's § 316(b) rulemaking activities by Science Applications International Corporation (SAIC) (SAIC, 1994; SAIC, 1995; SAIC, 1996a and b).

a. Intake location

Two major components of a CWIS's location that influence the relative magnitude of I&E are (1) the type of waterbody from which a CWIS is withdrawing water, and (2) the placement of the CWIS relative to sensitive biological areas within the waterbody. Considerations in siting include intake depth and distance from the shoreline in relation to the physical, chemical, and biological characteristics of the source waterbody. In general, intakes located in nearshore areas (riparian or littoral zones) will have greater ecological impacts than intakes located offshore, since nearshore areas are usually more biologically productive and have higher concentrations of aquatic organisms.

Figure A1-2: Conceptual Model Indicating Some Primary and Secondary Effects of Impingement and Entrainment by CWIS

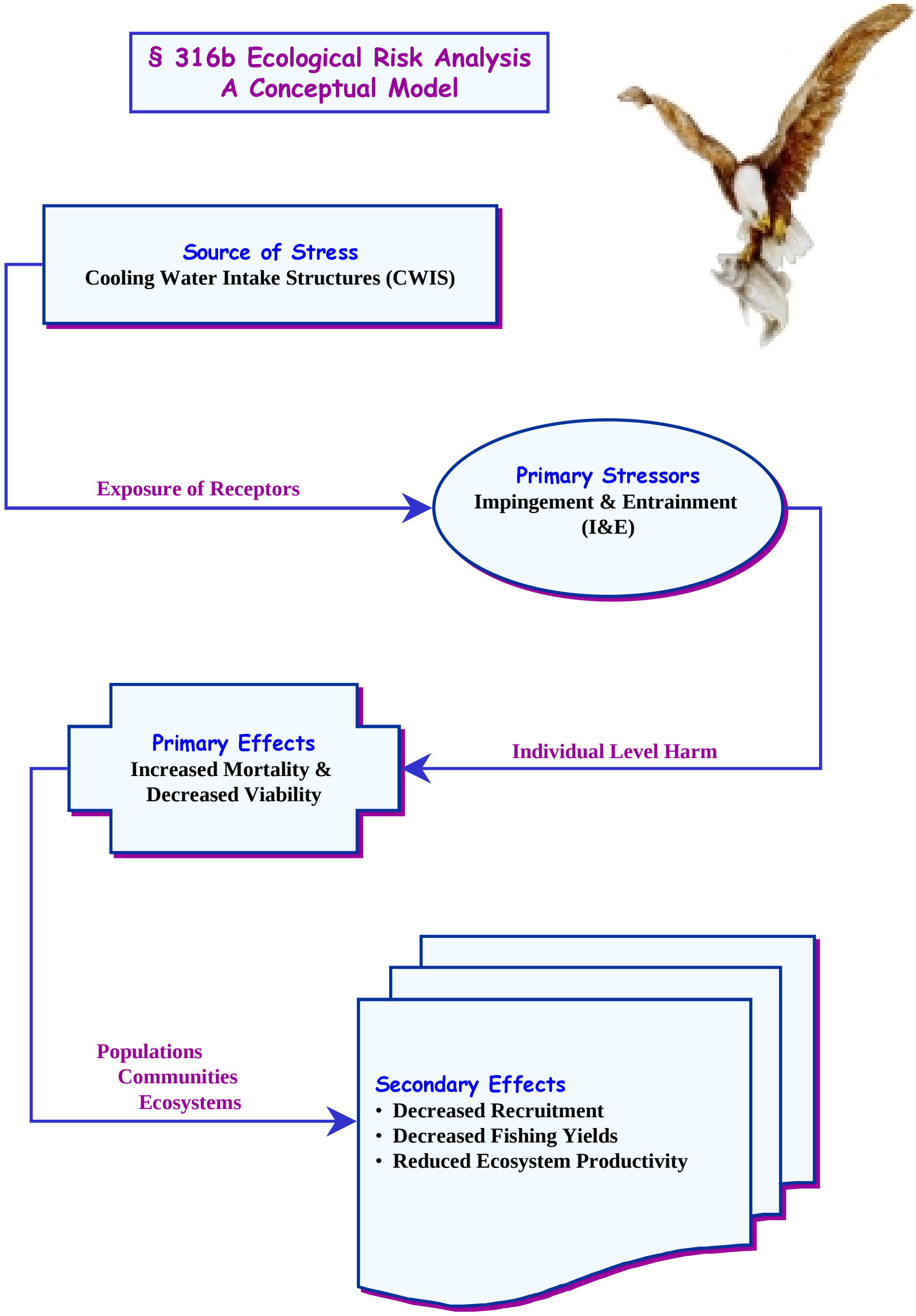


Table A1-1: Partial List of CWIS Characteristics and Ecosystem and Species Characteristics Influencing Exposure to I&E

CWIS Characteristics	Ecosystem and Species Characteristics
▸ Depth of intake ▸ Distance from shoreline ▸ Proximity of intake withdrawal and discharge ▸ Proximity to other industrial discharges or water withdrawals ▸ Proximity to an area of biological concern ▸ Type of intake structure (size, shape, configuration, orientation) ▸ Approach velocity ▸ Presence/absence of intake control and fish protection technologies a. Intake screen systems b. Passive intake systems c. Fish diversion/avoidance systems ▸ Water temperature in cooling system ▸ Temperature change during entrainment ▸ Duration of entrainment ▸ Use of intake biocides and ice removal technologies ▸ Scheduling of timing, duration, frequency, and quantity of water withdrawal ▸ Mortality of aquatic organisms ▸ Displacement of aquatic organisms ▸ Destruction of habitat (e.g., burial of eggs deposited in stream beds, increased turbidity of water column) ▸ Type of withdrawal - once through vs. recycled (cooling water volume and volume per unit time) ▸ Ratio of cooling water intake flow to source water flow	**Ecosystem Characteristics (abiotic environment)**: ▸ Source waterbody type (marine, estuarine, riverine, lacustrine) ▸ Water temperatures ▸ Ambient light conditions ▸ Salinity levels ▸ Dissolved oxygen levels ▸ Tides/currents ▸ Direction and rate of ambient flows **Species Characteristics (physiology, behavior, life history)**: ▸ Density in zone of influence of CWIS ▸ Spatial and temporal distributions (e.g., daily, seasonal, annual migrations) ▸ Habitat preferences (e.g., depth, substrate) ▸ Ability to detect and avoid intake currents ▸ Swimming speeds ▸ Body size ▸ Age/developmental stage ▸ Physiological tolerances (e.g., temperature, salinity, dissolved oxygen) ▸ Feeding habits ▸ Reproductive strategy ▸ Mode of egg and larval dispersal ▸ Generation time

Critical physical and chemical factors related to siting of an intake include the direction and rate of waterbody flow, tidal influences, currents, salinity, dissolved oxygen levels, thermal stratification, and the presence of pollutants. The withdrawal of water by an intake can change ambient flows, velocities, and currents within the source waterbody, which may cause organisms to concentrate in the vicinity of an intake or reduce their ability to escape a current. Effects vary according to the type of waterbody and species present.

In large rivers, withdrawal of water may have little effect on flows because of the strong, unidirectional nature of ambient currents. In contrast, lakes and reservoirs have small ambient flows and currents, and therefore a large intake flow can significantly alter current patterns. Tidal currents in estuaries or tidally influenced sections of rivers can carry small, passive organisms past intakes multiple times, thereby increasing their probability of entrainment. If intake withdrawal and discharge are in close proximity, entrained organisms released in the discharge can become re-entrained.

The magnitude of I&E in relation to intake location also depends on biological factors such as species' distributions and the presence of critical habitats within an intake's zone of influence. Species with planktonic (free-floating) early life stages have higher rates of entrainment because they are unable to actively avoid being drawn into the intake flow.

b. Intake design

Intake design refers to the design and configuration of various components of the intake structure, including screening systems (trash racks, pumps, pressure washes); passive intake systems; and fish diversion and avoidance technologies (U.S. EPA, 1976). After entering the CWIS, water must pass through a screening device before entering the power plant. The screen is designed, at a minimum, to prevent debris from entering and clogging the condenser tubes. Screen mesh size and velocity characteristics are two important design features of the screening system that influence the potential for impingement and entrainment of aquatic organisms that are withdrawn from the water body with the cooling water (U.S. EPA, 1976).

Approach velocity has a significant influence on the potential for impingement (Boreman, 1977). Approach velocity is the velocity of the current in the area approaching the screen and is measured at the screen upstream of the screen face in feet per second (fps). Approach velocity is directly related to the area of the screen and the size of the intake structure (U.S. EPA, 1976). The biological significance of approach velocity depends on species-specific characteristics such as fish swimming ability and endurance. These characteristics are a function of the size of the organism and the temperature and oxygen levels of water in the area of the intake (U.S. EPA, 1976). The maximum velocity protecting most small fish is 0.5 fps, but lower velocities will still impinge some fish and entrain eggs and larvae and other small organisms (Boreman, 1977).

Conventional traveling screens have been modified to improve fish survival of screen impingement and spray wash removal (Taft, 1999). However, a review by SAIC of steam electric utilities indicated that alternative screen technologies are usually not much more effective at reducing impingement than the conventional vertical traveling screens used by most steam electric facilities (SAIC, 1994). An exception may be traveling screens modified with fish collection systems (e.g., Ristroph screens). Studies of improved fish collection baskets at the Salem Generating Station showed increased survival of impinged fish (Ronafalvy et al., 2000).

Passive intake systems (physical exclusion devices) screen out debris and aquatic organisms with minimal mechanical activity and low withdrawal velocities (Taft, 1999). The most effective passive intake systems are wedge-wire screens and radial wells (SAIC, 1994). A new technology, the filter fabric barrier system (known commercially as the Gunderboom) consists of polyester fiber strands pressed into a water-permeable fabric mat, has shown promise in reducing entrainment of ichthyoplankton (free-floating fish eggs and larvae) at the Lovett Generating Station on the Hudson River (Taft, 1999).

Fish diversion/avoidance systems (behavioral barriers) take advantage of natural behavioral characteristics of fish to guide them away from an intake structure or into a bypass system (SAIC, 1994; Taft, 1999). The most effective of these technologies are velocity caps, which divert fish away from intakes, and underwater strobe lights, which repel some species (Taft, 1999). Velocity caps are used mostly at offshore facilities and have proven effective in reducing impingement (e.g., California's San Onofre Nuclear Generating Station, SONGS).

Another important design consideration is the orientation of the intake in relation to the source waterbody (U.S. EPA, 1976). Conventional intake designs include shoreline, offshore, and approach channel intakes. In addition, intake operation can be modified to reduce the quantity of source water withdrawn or the timing, duration, and frequency of water withdrawal. This is an important way to reduce entrainment. For example, larval entrainment at the San Onofre facility was reduced by 50% by rescheduling the timing of high volume water withdrawals (SAIC, 1996a).

c. Intake capacity

Intake capacity is a measure of the volume of water withdrawn per unit time. Intake capacity can be expressed as millions of gallons per day (MGD), or as cubic feet per second (cfs). Capacity can be measured for the facility as a whole, for all of the intakes used by a single unit, or for the intake structure alone. In defining an intake's capacity it is important to distinguish between the design intake flow (the maximum possible) and the actual operational intake flow.

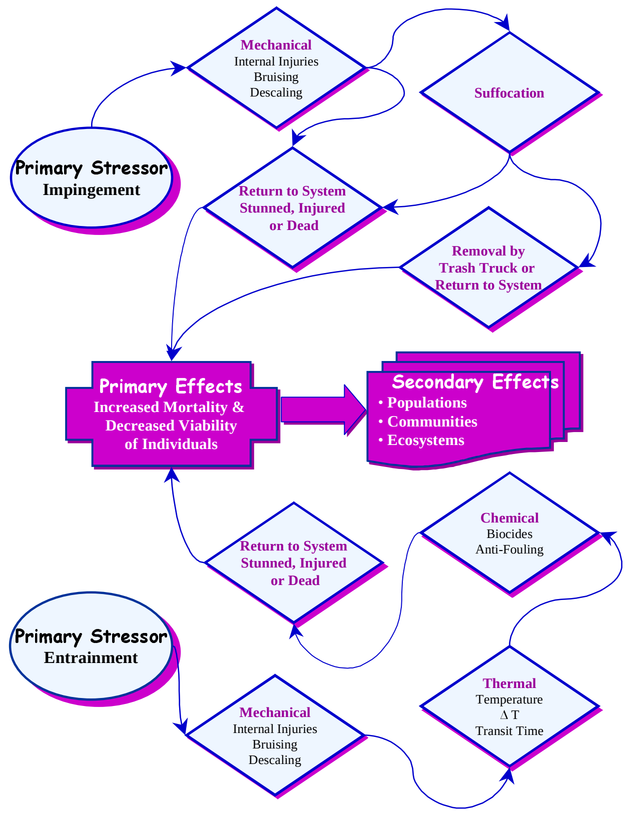
The quantity of cooling water needed and the type of cooling system are the most important factors determining the quantity of intake flow (U.S. EPA, 1976). Once-through cooling systems withdraw water from a natural waterbody, circulate the water through condensers, and then discharge it back to the source waterbody. Closed-cycle cooling systems withdraw water from a natural waterbody, circulate the water through the condensers, and then send it to a cooling tower or cooling pond before recirculating it back through the condensers. Because cooling water is recirculated, closed-cycle systems reduce intake water flow substantially. It is generally assumed that this will result in a comparable reduction in I&E (Goodyear, 1977b). Systems with helper towers reduce water usage much less. Plants with helper towers can operate in once-through or closed-cycle modes.

Circulating water intakes are used by once-through cooling systems to continuously withdraw water from the cooling water source. The typical circulating water intake is designed to use 1.06-3.53 cfs (500-1500 gallons per minute, gpm) per megawatt (MW) of electricity generated (U.S. EPA, 1976). Closed cycle systems use makeup water intakes to provide water lost by evaporation, blowdown, and drift. Although makeup quantities are only a fraction of the intake flows of once-through systems, quantities of water withdrawn can still be significant, especially by large facilities (U.S. EPA, 1976).

If the quantity of water withdrawn is large relative to the flow of the source waterbody, a larger number of organisms is more likely to be affected by a facility's CWIS. Thus, the proportion of the source water flow supplied to a CWIS is often used to derive a conservative estimate of the potential for adverse impact (e.g., Goodyear, 1977b). For example, withdrawal of 5% of the source water flow may be expected to result in a loss of 5% of planktonic organisms based on the assumption that organisms are uniformly distributed in the vicinity of an intake. Although the assumption of uniform distribution may not always be met, when data on actual distributions are unavailable, simple mathematical models based on this assumption provide a conservative and easily applied method for predicting potential losses (Goodyear, 1977b).

A1-2.2 Characterization of Ecological Effects

Figure A1-3: Stressor-Effects Pathway



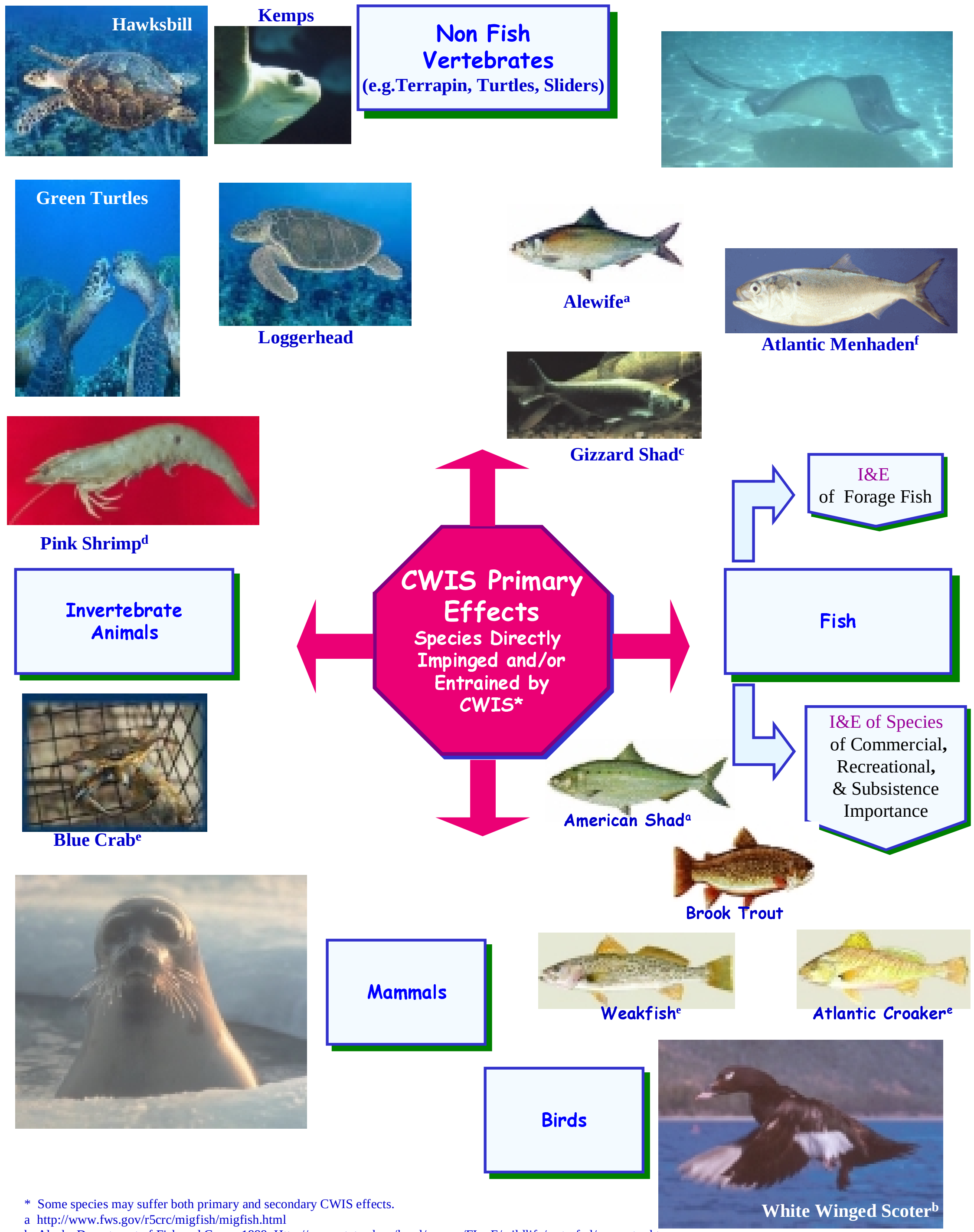
The characterization of ecological effects involves describing the effects resulting from the stressor(s) of interest, linking effects to assessment endpoints, and measuring endpoints to evaluate how effects change as a function of changes in stressor levels (U.S. EPA, 1998b). For EPA's § 316(b) case studies, measures of ecological effects included measures of both primary and secondary effects (Figure A1-3). Losses of impinged and entrained organisms are measures of primary effects and are the most direct measure of the effects of CWIS on aquatic organisms. It is necessary to fully evaluate primary effects in order to evaluate the consequences of these losses for fishery yields, ecosystem production, or other measures of indirect or secondary effects. The measurement endpoints evaluated for the § 316(b) case studies are discussed in detail in Chapter A4.

A1-3 RISK CHARACTERIZATION

The final step of an ecological risk assessment is the characterization of risk (U.S. EPA, 1998b). Risk refers to the likelihood of an undesirable ecological effect resulting from the stressor of concern. Because of the intrinsic variability and inevitable uncertainty associated with the evaluation of ecological phenomena, ecological impacts cannot be determined exactly, and thus only the probability (or risk) of an effect can be assessed (Hilborn, 1987; Burgman et al., 1993).

Risk can be defined qualitatively or quantitatively, depending on factors such as the goals of a risk manager and data availability (U.S. EPA, 1998b). Qualitative assessments usually involve best professional judgment. Quantitative assessments involve calculation of the change in risk (Ginzburg et al., 1982; Akçakaya and Ginzburg, 1991). The ecological risk assessments for EPA's § 316(b) case studies used available facility data to quantitatively evaluate impingement and entrainment risks to aquatic organisms.

Figure A1-4: Examples of Species Directly Affected by CWIS



* Some species may suffer both primary and secondary CWIS effects.
a http://www.fws.gov/r5crc/migfish/migfish.html
b Alaska Department of Fish and Game, 1999. Http://www.state.ak.us/local/apages/FI…E/wildlife/waterfwl/wwscoter.htm
c http://www.gen.umn.edu/faculty_staff/hatch/fishes/gizzard_shad.html
d http://www.dnr.state.sc.us/marine/mrri/seamap/pduo.htm
e http://www.chesapeakebay.net/
f South Carolina Department of Natural Resources, 2001.